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PETROLOGICAL ABSTRACTS AND REVIEWS

CHARLES H. BEHRE, JR.

FERGUSON, J. B., and MERWIN, H. E. "The Melting Points of Christobalite and Tridymite," *Amer. Jour. Sci.*, XLVI (1918), 417–26, figs. 2.

A description of experimental methods employed in testing the melting points of these two minerals. A high-temperature furnace, built on the cascade principle, and capable of maintaining a temperature of 1700° for several hours, is described. By means of this furnace quartz has been inverted directly through dry heat alone. The melting point of tridymite has been determined (for the first time) as $1670° \pm 10°$ C.; that of christobalite has been redetermined; it is $1710° \pm 10°$ C. Christobalite is stable at higher temperatures than tridymite as determined earlier by Fenner.

FERGUSON, J. B., and MERWIN, H. E. "Wollastonite ($CaO.SiO_3$) and Related Solid Solutions in the Ternary System Lime-Magnesia-Silica," *Amer. Jour. Sci.*, XLVIII (1919), 165–89, figs. 8.

A further experimental study of the liquidus curves for the system of these three oxides, though not completely quantitative, yet confirms the earlier work with the same system, demonstrates the existence of solid solutions of diopside up to the amount of 16 per cent in pseudowollastonite and diopside, and of åkermanite in wollastonite and pseudowollastonite. A new compound—$5\,CaO.2MgO.6SiO_2$—is reported. The paper contains also a fairly complete discussion of results obtained in the curves derived, and photographs of the solidus-liquidus concentration-temperature models.

FERGUSON, J. B., and MERWIN, H. E. "The Ternary System $CaO.MgO.SiO_2$," *Amer. Jour. Sci.*, XLVIII (1919), 82–123, figs. 19.

This is the most complicated system of any that can be constructed of three of the four oxides, CaO, MgO, Al_2O_3, and SiO_2. Försterite, diopside, enstatite, tridymite, cristobalite, lime, magnesia, pseudowollastonite, and two compounds of the three oxides were obtained. Solid solutions of five types were also recognized in crystalline form; these included clino-enstatite-diopside solutions, pseudowollastonite solutions of varying composition, wollastonite solutions, solutions of an unnamed compound of the three oxides, and menticellite solutions. Scholler's åkermanite could not be prepared, but $5CaO.2MgO.6SiO_2$ and $2CaO.MgO.2SiO_2$ were recognized for the first time. The tridymite-cristobalite inversion temperature is essentially 1470° C., but measured with difficulty because of the great sluggishness of the inversion.

FERGUSON, J. B. "The Oxidation of Lava by Steam," *Jour. Washington Acad. Sci.*, IX (1919), 539–46.

Demonstrates experimentally that the formerly generally supposed oxidizing power of steam in lavas is not effective. Hence volcanoes may give off lava bearing ferrous iron and yet discharge large amounts of steam.

FLÖRKE, WILHELM: *Über die kunstliche Verwitterung von Silikatgesteinen unter dem Enfluss von schwefliger Säure.* Giessen, 1915. Pp. 32.

This is a study of the action of sulphur dioxide on coarse-grained igneous rocks. Experiments were carried on in the presence of water. All types of rock, varying from granite to gabbro, were attacked by the SO_2 vapors. The ferro-magnesian minerals were most corroded, hence the basic rocks also suffered most. Soluble sulphates of aluminum, iron, manganese, calcium, magnesium, sodium, and potassium were produced, as well as insoluble hydroxides of aluminum and iron.

FOYE, WILBUR GARLAND: "Geological Observations in Fiji," *Proc. Amer. Acad. Arts and Sci.*, No. 1, LIV (1918), 1–145, bibliography, figs. 40, pls. 1; in two parts.

A summary of the geology and petrology of the Fiji Islands is here presented. The group consists of two larger islands, Viti Levu and Vanua Levu, having central cores of deeply eroded plutonic rocks and possibly representing an earlier continental mass, and of several smaller fringing land masses. Four periods of vulcanism are recognized, the first being rhyolitic, the last basaltic, and the two intermediate ones andesitic. On Viti Levu a series of Miocene (?) sediments is much folded and overlain on the coastal plains by gently dipping post-Tertiary beds. On Vanua Levu are Pleistocene or recent coastal plain limestones and volcanics. Here subsidence has been generally accompanied by reef formation. An extended discussion of the coral reef question is given and a modification of Darwin's hypothesis thought to be favored in some measure.

The history may be summarized as follows:

9. Subsidence.
8. Basaltic intrusions and extrusions.
7. Uplift and erosion of (6).
6. Subsidence, with the deposition of about 150 feet of limestones and marls.

5. Second period of volcanic eruption, with subsequent erosion.
4. Uplift and erosion of (3).
3. Subsidence and deposition of limes, sands, and clays.
2. Andesitic lavas extruded, later eroded.
1. Plutonic intrusives, eroded to late maturity.

The first part of the paper describes the general geology of the islands; the foregoing is a brief summary. The second part discusses the petrography of the region studied. The important sediments are chiefly calcareous, but some conglomerate is known—river gravel, with bowlders of all sorts, and a calcareous conglomerate with over 50 per cent igneous bowlders but much shell-waste in the cement. The igneous rocks described are chiefly andesites and basalts, of which the latter preponderate in the descriptions.

Some of the extrusions were submarine, marked generally by the presence of hornblende; this character almost appears to be diagnostic of the subaqueous origin of such flows as bear it. Another interesting feature is the persistent association of hypersthene and hornblende.

The first andesitic period is recognized only on the two large islands. The flows of the second andesitic period are widespread and may be essentially synchronous in origin with some basalts and rhyolites. The lavas of the basaltic period, again, are more limited in their distribution. In general, differentiation in Fiji progressed from acid to basic. Volcanic vents have been singularly persistent, the basaltic flows seldom or never forming cones of their own. Ten rock analyses are presented, but no modes are given and only a few of the rocks are classified according to the norm system.

GOLDSCHMIDT, V. M. *Die Gesetze der Gesteinsmetamorphose, mit Beispielen aus der Geologie des Südlichen Norwegens.* Christiania, 1912. Pp. 16, fig. 1.

A concise application of the laws of thermodynamics to metamorphism. The "mineralogical phase rule" states that in a stable combination as many minerals may be formed as there are variables in the system. Thus in a mixture of silica, magnesia, and alumina only three minerals may be developed. The conditioning agents in contact metamorphism are pressure and temperature. By plotting the pressure horizontally and the temperature vertically, various fields are obtained which are either gradational or sharply marked off from each other. The melting temperatures of the more refractory minerals limit the phase-curve above. The effect of pressure is well illustrated by grossularite, which requires a higher pressure to maintain its identity at high temperatures than at low ones; its compact atomic structure is also favorable to stability at high pressures. Separate curves for each system may be prepared by applying the third principle of thermodynamics, Nernst's theorem; the approximate formula used in calculating the curve is from the same investigator. Such a curve applied to the system $CaO.SiO_2.CO_2$ yields a change from calcium carbonate and quartz at lower temperatures (mean about 900° C.) to wollastonite and carbon dioxide. This and similar rules are exemplified by the crystalline schists of the Christiania region.

GOLDSCHMIDT, V. M. *Das Devongebiet am Röragen bei Röres.* With a paleontological supplement: NATHHORST, A. G. *Die Pflanzenreste der Röragen-Ablagerung.* Christiania, 1913. Pp. 27, pls. 5, maps 2, figs. 3.

This is a report on the areal and structural geology of an area measuring about 10 by 7 kilometers in south-central Norway, bounded on the north by the Lake of Betnen, on the south by the Lake of Feragen. The sedimentaries shown here are Cambrian, Ordovician, and Devonian, the last composing by far the greater part. Granite, augen-gneiss, saussuritized gabbro, and basic peridotite-serpentines are the igneous rocks. Chromite has been mined in the last-named rock. The Devonian beds overlie unconformably the eruptives and older sedimentaries; they consist of conglomerates, sandstones, and slates. An especially interesting member of the Devonian sequence is a 200-meter-thick serpentine conglomerate, of which the angular bowlders resemble breccia-fragments of serpentine; at its base it goes over locally into white magnesite. The total thickness of the Devonian is about 400–500 meters.

Faulting has affected the pre-Caledonian sediments, and this was followed by a period of intrusion from which date the eruptive rocks mentioned above. The pre-Devonian beds dip toward the northwest.

Devonian beds, however, have a general southeasterly dip. These sediments were probably deposited in a basin or basins of limited extent, formed and filled during the middle Devonian.

Illustrative plates and a brief description of the Devonian floras of the region accompany the report.

GOLDSCHMIDT, V. M. "Über einen Fall von Natronzufuhr bei Kontaktmetamorphose," *Neues Jahrb.*, XXXIX (1914), 193–224, pl. 1.

A study of contact metamorphism in sandstones of Norway. The unmetamorphosed sandstones are somewhat arkosic (microperthite, albite, orthoclase, and microcline are the feldspars) and flakes of muscovite and chlorite are also present; the matrix is calcareous or argillaceous. These sandstones are Devonian or Silurian in age. When metamorphosed they normally become biotite-rich quartzite or even hornfels. Wollastonite is commonly developed. In other instances secondary potash feldspars, sometimes intercrystallized with plagioclase, appear in the matrix. Besides quartz, a pyroxene (hedenbergite) is very common. This description characterizes the normal type of metamorphism.

An entirely distinct type of metamorphism, common along the borders of pegmatite dikes, is conspicuous in the presence of aegirite and riebeckite, as well as of long, needle-like titanite crystals. The latter, as well as the soda-rich pyroxene and amphibole, are attributed to an increase in soda-content, with a corresponding decrease in calcium oxide. The formation of aegirite and riebeckite takes place especially in the absence of alumina.

GOLDSCHMIDT, V. M. *Geologisch–Petrographische Studien in Hochgebirge des Südlichen Norwegens: III, Die Kalksilikatgneise und Kalksilikatglimmerschiefer des Trondhjem-Gebiets*, Christiania, 1915. Pp. 37, pls. (and maps) 2, table 1.

This is a summary of investigations in the zone of the Gula gneisses and slates of the Trondhjem district, Norway. The Gula group is probably of Silurian age. The rocks are highly metamorphosed, and the particular facies here studied are those rich in calcium silicates. Several zones of the schists are recognized, varying in their chlorite and biotite content. The results of extreme metamorphism may be summarized as follows: (*a*) Highly calcareous rocks lose their biotite content, this being replaced by plagioclase, amphibole (or pyroxene), and potash feldspar; or, (*b*) If poor in calcium oxide, the rocks are converted into a biotite-plagioclase rich slate, with varying amounts of quartz. In the former case the rock texture and constituents vary markedly with variations in degree of metamorphism. The latter type may be readily shown to be of sedimentary origin by means of microscopic study, corroborated by chemical analysis. Methods given in the text for calculating the theoretical constitution of these meta-sedimentaries are most instructive.

GOLDSCHMIDT, V. M. *Geologisch-Petrographische Studien im Hochgebirge des Südlichen Norwegens: IV, Übersicht der Eruptivgesteine im Kaledonischen Gebirge zwischen Stavanger und Trondhjem.* Christiania, 1916. Pp. 140, pls. (and maps) 7, table 1, figs. 2. .

Reports the petrologic findings in an area about 600 kilometers long lying between Stavanger and Meraker, in southern Norway. This area bears igneous rocks of all sorts, from acid to basic. It is impossible to treat these as though they were all products of a single magmatic province; more probably they belong to three separate groups, as follows: (1) Green lavas, tuffs, and intrusives—the differentiation products being chiefly basic; (2) Anorthosite-charnokite rocks, with numerous differentiation products; and (3) Tonalite-granodiorite magmas, with many differentiation products. Some few of the rocks, indeed, do not even fit into such a classification.

In the first group are lavas, tuffs, agglomerates, and dike-rocks. Pillow-lavas are common. The intrusives of this group are gabbros and olivine-rich rocks. These are often saussuritized, uralitized, or converted into serpentine. Analyses of members of this class, as well as of the two others, are presented. The green lavas probably range in time from the upper part of the Ordovician into the Silurian; they are apparently homologues of the greenstones of England and Wales, which, however, were extruded at a slightly earlier date.

The anorthosite-charnokite rocks vary greatly in character. Some are typical gabbros and norites, others bear a little potash feldspar. Uralitization is common here.

Masses of pyroxenites and peridotites also belong to this period; these generally appear as lenses enclosed in basic or intermediate masses of more recently consolidated magmas of the same group. Another type of rock found here is labradorite-rich, hypersthene-bearing "labradorfels" (=anorthosite). All the above rocks of this segregation group are basic. There are also norites and mangerites; hypersthene-syenites represent a gradation toward the more alkalic end of the series; and finally acid rocks are represented by granites—hypersthene-granite (birkremite), commonly showing droplet-like plagioclase within the potash feldspar, augite-granite, diopside-granite, aegirite-granite, amphibole-granite, and biotite-granite, the latter two forming the commonest acid rocks of the group. Pegmatites and dike-rocks are common, and the latter range from acid to basic (peridotites). The sequence in the anorthosite-charnokite group is known with certainty to be (1) pyroxenite-peridotite, gabbro and norite, (2) norite, mangerite, and labradorite, (3) pyroxene-syenite, monzonite, and granite.

These anorthosite-charnokite rocks appear to have played a noteworthy part in the diastrophism of the region. They are assigned to early Caledonian age.

The third group studied comprises pyroxenites, peridotites, and gabbros; intermediate rocks, too, such as diorites, hypersthene-mica-diorites, and a peculiar type newly called "opdalite," which appears to be essentially a quartz-diorite. The acid phase is represented by "trondhjemite," (new name) which Kjerulf calls an oligoclase-granite, and which might as well be characterized as a granodiorite. Associated with these rocks are some dike-rocks, which incline generally toward the acidic; thus trondhjemite-porphyries, -aplites, and -pegmatites are recognized. The porphyritic phases occur already as borders of the larger intrusive masses.

A noteworthy fact is the sharp boundary of these aplites against the schistose basic country rock. This is explained by applying the principles of differentiation through fractional crystallization. A granite which has differentiated and achieved stability through having the basic constituents of the mother magma crystallize out, cannot resorb similar basic components; a magma can only assimilate the country rock when the mineral constituents of the latter have not been previously lost by differentiation in the mother magma.

Most of the rocks of the trondhjemite character are laccoliths or laccolithic. They all appear to be post-Ordovician; they may be described in general as of Caledonian (Upper Silurian) age.

Many rocks do not definitely fit into any of the foregoing three groups. These include pyroxenites, gabbroid types, basic and normal diorites, tonalite, granites, and their aschistic and diaschistic differentiates. This group may, if the sequence be as given above, indicate progressive differentiation. They occur south of the Trondhjemfjord. Granites are found on the west coast, too, and here are definitely assignable to Caledonian age, but cannot be readily placed in a magmatic province. Some augengneisses are also assigned to the same period.

As to the consanguinity of the three main groups recognized above, nothing definite can as yet be stated; surely the relationship is not as close between the separate groups as within each group. Each group, however, illustrates beautifully the differentiation-parallelism of separate magmas. Whether or not they *are* related might perhaps be answered by calculating the general composition of each group from a study of the rock-components. Data for such a calculation is, in the opinion of Doctor Goldschmidt, not yet sufficiently complete to undertake any generalizations. This is unfortunate, for here is a large geographic province which might furnish the best of examples for a study of magma-relationships and petrographic provinces in time if not in space.

Rocks similar to the green lavas occur in Scotland, and others like the Bergen-Jotun-granites (Group 2, above) are recognized from Sweden. The third group (called by Goldschmidt the opdalite-trondhjemite group) is undoubtedly represented in southern Scotland by the Galloway granite of Peach, Horne, and Teall, the age of which is less than the Ludlow and greater than the Old Red.

The writer seeks to draw analogies between the petrographic character of the rocks in the Stavanger-Trondhjem district and those elsewhere, especially in the Alps.

Twenty-two analyses of typical representatives of the several groups are appended, and many more, sometimes recalculated, are incorporated in the text.

GOLDSCHMIDT, V. M. *Geologish-Petrographische Studien im Hochgebirge des Südlichen Norwegens: V, Die Injektionsmetamorphose im Stavanger-Gebiete.* Christiania, 1921. Pp. 142, pls. 15, map (with separate legend) 1, with numerous tabulated analyses.

The rocks in this district are of several periods. At the base of the section are pre-Cambrian rocks, unconformable below Cambro-Silurian deposits. The latter consist of phyllites of Cambrian and lower Ordovician age and of green slates of the upper Ordovician and Silurian. These are followed by eruptives of Caledonian age, which are partly green lavas, partly members of the opdalite-trondhjemite group discussed in a previous paper. Locally on the borders of the district are conglomerates, arkoses, and sandstones essentially of Downtonian age (Upper Silurian). Still younger dikes of diabase traverse the other rocks, and Quaternary sands and clays, partly glacial, are the last deposits to be laid down.

The pre-Cambrian rocks are chiefly granitic, with lesser amounts of amphibolites. Structurally they represent a major syncline, the axis of which parallels the trend of the Caledonides, i.e., runs northeast-southwest. The phyllite division of the Cambro-Silurian is definitely assigned to the Cambro-Ordovician on the basis of fossils occurring outside the area; it begins with a basal conglomerate, and passes into phyllites and calcareous strata, with local increase in sandy content. This phyllite division is at least 300 meters thick.

The green saltes are assigned to the Silurian also on the basis of fossil findings. These "slates" bear sandstones and conglomerates (rarely) and considerable amounts of limestone and dolomite (which may have been derived metasomatically from limestones), but metamorphosed clayey deposits are predominant among the sediments. Eruptive rocks are highly metamorphosed, so that they cannot always be assigned with certainty to volcanic origin.

Sedimentary rocks are known from the Caledonian; they consist of conglomerates, typical sandstones, arkoses, and similar types, derived largely from the pre-Caledonian and Caledonian effusives. Hence also these actually follow the Caledonian opdalite-trondhjemites and green lavas. A description of the first of these two Silurian types is to be found in the preceding review; both basic and acid rocks are known, the latter including adamellite, granite, and quartz-pegmatite.

The Cambro-Silurian rocks were deposited on a peneplained surface. This period of sedimentation was followed by one of intrusion—that of the opdalite-trondhjemite group, either synchronously with or slightly preceding the Caledonian mountain-building, during which sediments and intrusives alike were folded and fractured, the magmas perhaps being deformed even before complete congealing. Finally in late Caledonian times there was extensive faulting of all the rocks of the Stavanger District.

A study of the opdalite-trondhjemite masses of Stavanger demonstrates that the larger intrusives are limited to the boundary between the phyllites and the overlying green slates. These actually represent one type of structure, whereas an entirely different type is indicated by flat-lying masses of intrusives that seem to have been more severely displaced during cooling. In the Stavanger District the two types of structures, one representing igneous rocks cooled in place, the other those cooled after some dynamic action, lie close together; of these the distorted and "dynamo-transported" masses are by far the more common.

After this general discussion of the geology of the region, the writer proceeds to a description ot the metamorphism that has affected the rocks, with special regard for the injection-metamorphism that borders the opdalite-trondhjemite type of rocks. The clayey sediments have undergone regional metamorphism ranging in its products from the mere development of good cleavage, through the development of garnet-mica-schists, and finally the growth in these of basic plagioclase and of pyroxenes.

Most distantly from the borders of the acid masses the phyllite becomes altered to garnet; farther in toward the intrusive this is replaced by biotite, thus presenting an order that is the reverse of that more commonly observed. There is also a progressive increase in sodium content as the intrusions are approached. Closer yet microperthite makes its appearance. These rocks are in turn altered to injected mica-schists and gneissic mica-schists; the "injected" schists are not so in the sense that a liquid magma has been forced inward along the lines of schistosity; injection, as here used, implies rather a metasomatism, with a relatively small addition of extraneous material.

The upper Silurian green slates, too, form significant "injection schists." Even the basic differentiates in the opdalite-trondhjemite series have undergone some contact alterations, because affected by the later acidic intrusions.

Various types of metamorphic rock are described in detail; these include quartz-muscovite-chlorite-phyllite, quartz-muscovite-chlorite-garnet-phyllite, quartz-muscovite-biotite-garnet-phyllite, chloritoid-slates, and albite-porphyroblastic schists. Transitions between these and "augengneisses" are also known. When acid material is added by injection, the albite-porphyroblastic rocks are altered to injection-(injected)gneisses. These are partly bedding-plane injection types, with marked parallelism in the texture of the crystalline injected rock, partly vein-injected gneisses, and augen-gneisses (which are attributed also to injection of clay slates by the more acid rock).

Much of the alteration is due especially to the addition of quartz, water, and soda. These may have been brought in as soluble sodium silicate.

The metamorphism here described is compared with that elsewhere in Europe and also with that in the Christiania District, which has been studied in detail. In the latter instance it is interesting to note the far greater regional distribution of the contact phases, attributed by Goldschmidt to the greater water content of the effective magmas. In the Stavanger District probably the most conspicuous thing is the extensive contact metamorphism of *siliceous* sediments. Into the same class of metamorphism, due essentially to chemical differences between the country rock and the "magma milk," falls that described by Brauns under the name of "pyrometamorphosis."

GORDON, SAMUEL W. "Ordovician Basalts and Quartz Diorites in Lebanon County, Pennsylvania," *Proc. Acad. Nat. Sci.*, Philadelphia, Nov., 1920. Pp. 354–57, figs. 5.

Includes the first report of Paleozoic volcanic rocks in the form of a basalt flow, from Lebanon County, Pennsylvania. Intrusive into the Martinsburg shale are sills and dikes of quartz diabase, to the northwest of which lie the interbedded basaltic flows. The quartz-diabase is a fine-grained dark greenish rock becoming very fine-grained at the contact; it may bear phenocrysts of augite, attaining a length of a centimeter; the texture is diabasic or ophitic, the labradorite being quite zoisitized.

The basalt is brecciated or tuffaceous and amygdaloidal, hence the flows were probably subaqueous; under the microscope the basalt breccia shows as a perlitic, dark greenish glass.

GUILD, F. N. "A Microscopic Study of the Silver Ores and Their Associated Minerals," *Econ. Geol.*, XII (1917), 297–353, pls. 11.

This paper represents a summary of rather extensive work done by Mr. Guild on silver ores from many localities, both here and abroad. The characteristic early minerals of silver deposits are pyrite, sphalerite, and arsenopyrite. These are chiefly hypogene in origin, though the first may also occur as a secondary mineral. They are commonly followed by the deposition of argentiferous galena and tetrahedrite; the order of deposition is arsenopyrite, pyrite, sphalerite, tetrahedrite, chalcopyrite, and galena. The later silver minerals that are discussed include stromeyerite, which exhibits exceedingly close "pseudo-eutectic" intergrowths, that may actually be eutectic in nature, pyrargyrite and proustite, stephanite, polybasite, argentite, and native silver. The latter certainly forms in some cases as a result of the breaking down of complex silver minerals. Other sources of silver are also briefly considered—cerargyrite and the rarer minerals huntlinite (silver arsenide), dyscrasite (silver antimonide), brogniardite (a complex sulphide of silver, lead, and antimony), and schirmerite (bismuth-silver-lead sulphide). Variously associated with the silver are chalcopyrite, bornite, chalcocite, and covellite. Commonly associated cobalt and nickel minerals are smaltite, niccolite, and breithauptite.

The predominant gangue minerals found with silver are carbonates—notably in the lead-silver type of ores; this indicates a tendency for such ore-minerals to come from neutral or alkaline solution, as carbonates could not be developed in acid solutions. The gangue minerals mentioned are calcite, dolomite, siderite, rhodochrosite and barite.

Excellent hints as to methods for distinguishing silver minerals microchemically are presented, a subject so far neglected only too often. Good manuals for the ore-geologist are indeed rare, and good manuals dealing with the microscopy of silver minerals are wholly lacking.

The paper contains interesting discussions of graphic intergrowth, of "enrichment" of silver ores, and of the composition of some important silver minerals. A table presents the investigator's ideas regarding the sequence of deposition of double salts of silver and other metals.